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Deformation of the Haley Creek Terrane, Southern Alaska:

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DEFORMATION OF THE HALEY CREEK TERRANE, SOUTHERN ALASKA: MESOZOIC TRANSCURRENT MOVEMENT ALONG THE SOUTHERN ALASKA MARGIN

by

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ABSTRACT

Detailed mapping along the TACT (Trans-Alaska-Crustal-Transect) corridor suggests that a retrograde mylonitic deformation in the Haley Creek Terrane records a Cretaceous dextral strike-slip shearing along the southern Alaska margin. Structural fabrics in the Haley Creek Terrane are characterized by a nearly horizontal east-west stretching lineation developed in a near vertical, east-west striking mylonitic foliation. Strain is variable however, in that many rocks are L-tectonites whereas elsewhere lineation is weakly developed. In areas of low strain, metaplutonic rocks are cut by numerous ductile-shear zones which generally show dextral movement, although locally the shear zones form conjugate sets. The latter presumably reflect a local flattening within an overall right-lateral shear system. In thin section, the rocks are very fine-grained, dynamically recrystallized rocks with seriate quartzo-feldspathic groundmasses. Microstructural observations, which include broken porphyroclasts and kinked micas, are used together with megascopic observations to substantiate the sense of shear. USGS geochronological studies in progress should clarify ages but existing K-Ar ages imply that the mylonitic deformation occurred in Early Cretaceous time. Until the absoulute ages are clarified however, the tectonic significance of these observations remains elusive.

INTRODUCTION

In recent years numerous authors have suggested that strike slip faulting played a major role in the Mesozoic tectonics of the northern Cordillera, yet there has been little hard geologic evidence for these speculations. In this paper I present evidence for extensive Mesozoic transcurrent movement along the Border Ranges Fault. Kinematic interpretations of a suite of mylonites located in the Haley Creek Terrane of south-central Alaska comprise the data.

The Paleozoic to Jurassic Haley Creek Terrane is a structurally complex tectonostratigraphic terrane lying along the Border Ranges Fault in the eastern Chugach Mountains. Mapping carried out as part of the 1984 Trans-Alaska-Crustal-Transect (TACT) project (Plafker et al, 1985) along with detailed mapping carried out by Wallace (1981) makes this one of the better mapped areas in the Chugach Mountains. This study is the result of detailed mapping of approximately 25 square miles of the Haley Creek Terrane conducted during the 1984 field season as part of the TACT studies.

Many of the major tectonic elements of southern Alaska are near the study area (figure 1-1). Thus it is in a key location in efforts to gain a better understanding of the Mesozoic tectonic evolution of south-central Alaska. In this paper my discussion emphasizes a mylonitic deformation, recognized by Wallace (1981), in the Haley Creek Terrane. This deformation is significant because it is this deformation which records non-coaxial shear in a zone of transcurrent movement. This report is based chiefly on observations and geologic data collected in the field. Microstructural observations and quartz c-axis data are also presented.

Since the study area lies in a rather remote area, transportation was

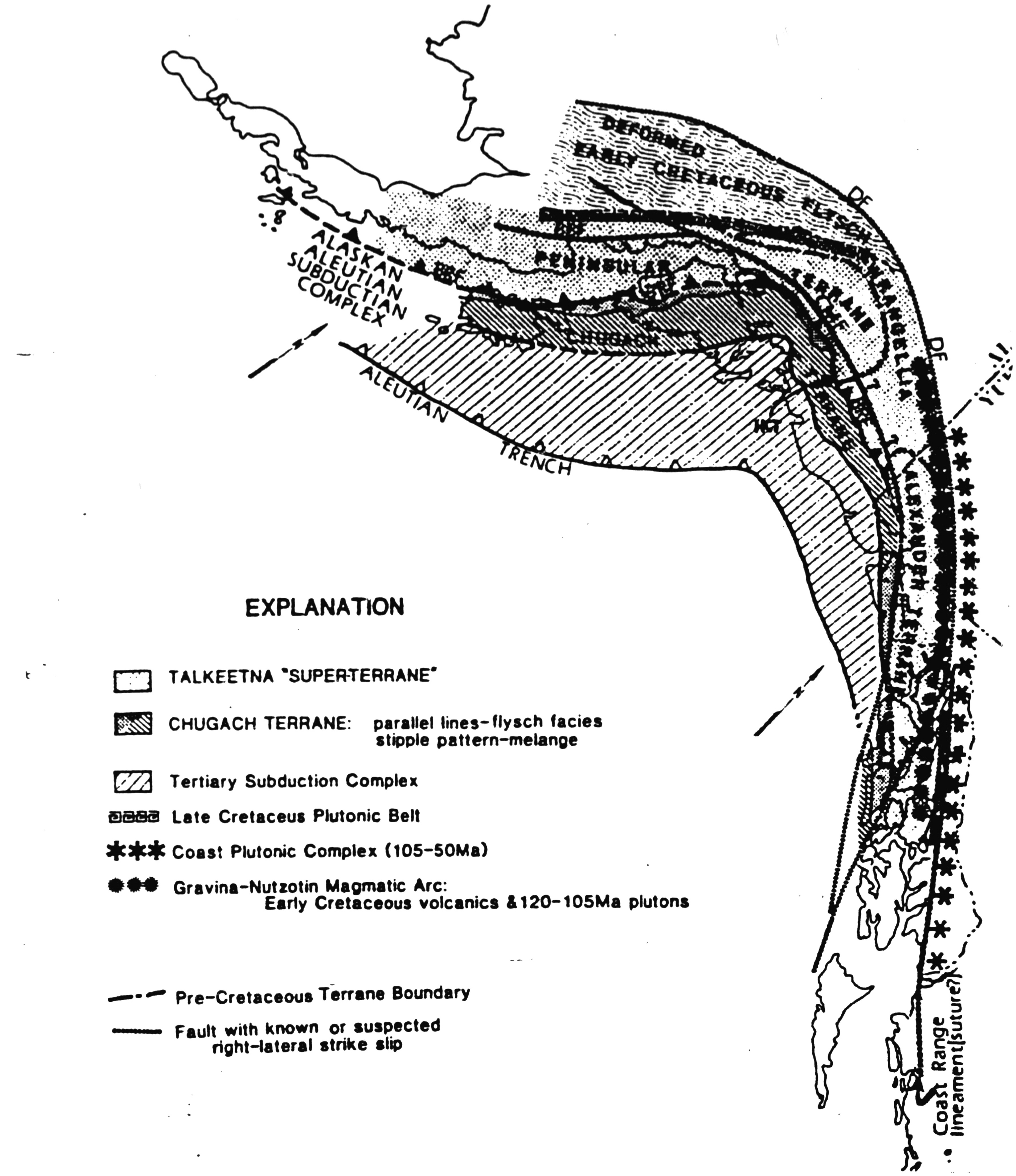


Figure 1-1: Major tectonic elements of southern Alaska. WT=Wrangellia, PT=Peninsular Terrane, AT=Alexander Terrane, CT=Chugach Terrane, DF=Denali Fault, CMF=Castle Mountain Fault, BRF=Border Ranges Fault (from Pavlis, 1982 as compiled from Jones and Siberling, 1979; Hudson, 1979; Berg and others, 1972; Monger and Price, 1979; Plafker and others, 1977; and Crawford and Hollister, 1982).

restricted to foot and helicopter travel only. Mapping was completed on U.S.G.S. quadrangle maps at a scale of 2 inches equal to 1 mile. Approximately 100 rock specimens were collected in the Haley Creek Terrane. Specimens showing typical or special features will be refered to throughout this report.

GEOLOGIC FRAMEWORK

Prior to this mapping program the Haley Creek Terrane received considerable attention from Wallace (1981) as the focus of his doctoral dissertation. Other work in the region pertaining directly to the study area includes reconnaissance work done by MacKevett and Plafker (1974) and 1:250,000 mapping of the Valdez Quadrangle by Winkler and others (1981).

Figure 2-1, taken from the summary of 1984 TACT geologic studies (Plafker et al, 1985), is a generalized map of the regional geology of the study area. The area mapped in detail as part of this report is outlined. The southern boundaries of the Peninsular Terrane and Wrangellia as well as the boundary between the two, lie to the north and east of the study area. In fault contact with the Haley Creek Terrane on all sides is the Valdez Group, an assemblage of phyllites and metasandstones of Late Cretaceous age. Progressing northward from the Haley Creek Terrane the rock sequence is typical of areas to the west along the Chugach front (Pessel et al, 1981; Burns et al, 1983; Pavlis, in press). Specifically, the Valdez Group lies structurally beneath an older melange terrane, the McHugh Complex, a chaotic assemblage of a number of rock types of Late Jurrasic to Early Cretaceous age including phyllites, metasandstones, and greenstones. The McHugh Complex is in turn thrust beneath the crystalline basement of the Peninsular Terrane (figure 2-1). Additional complications in this area include the presence of a slab of blueschist facies rock, the Liberty Creek Terrane, which may be a high pressure equivalent of the McHugh Complex, and an ultramafic sheet, the Tonsina Complex. The latter is thought to represent upper mantle rocks beneath the Peninsular Terrane arc (Burns, in press; Coleman and Burns, 1985).

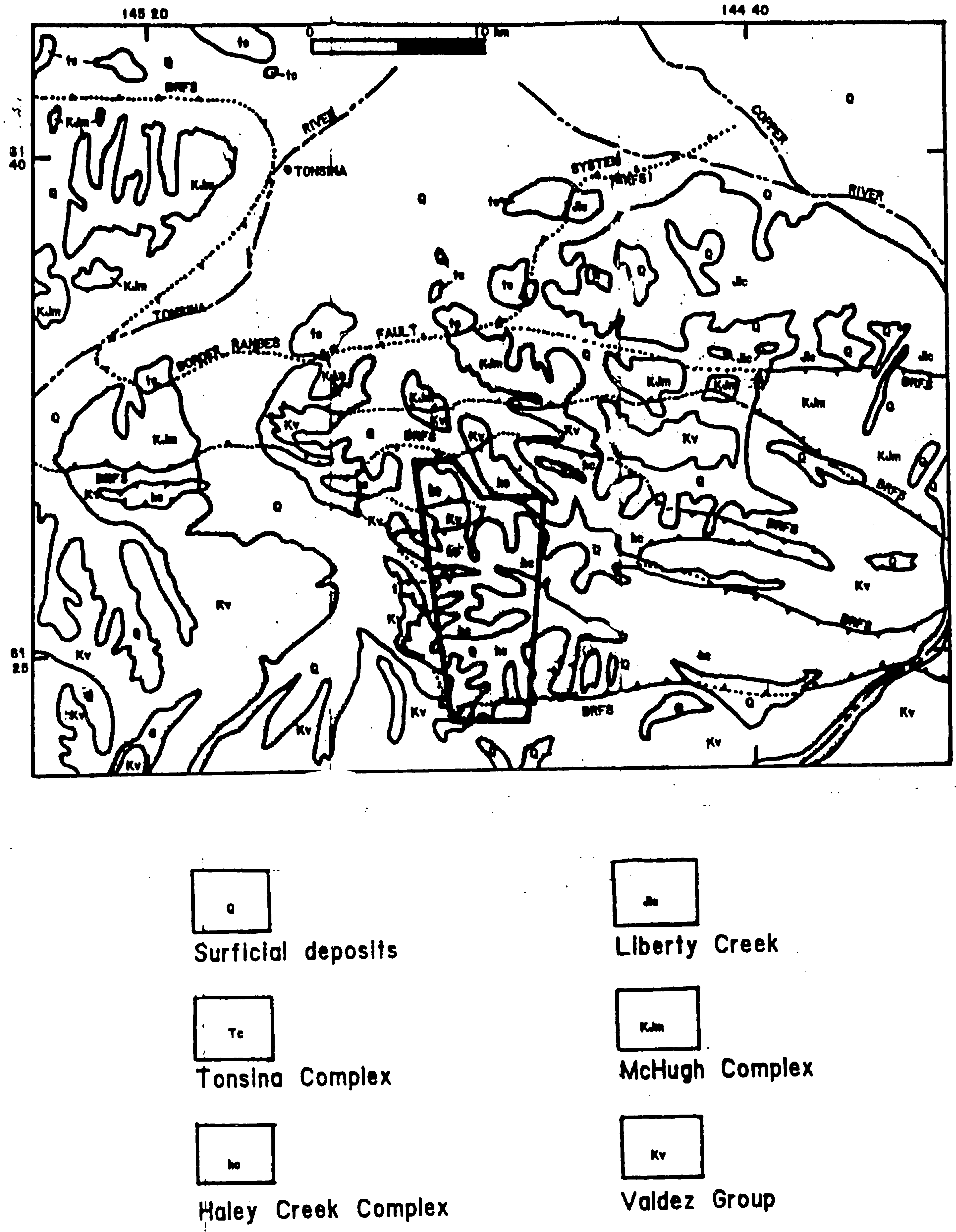


Figure 2-1: Generalized map of the regional geology of the study area. The area mapped in detail as part of this report is outlined (from Plafker et al, 1985).

The map area consists of a range in rock types which make up a major thrust plate. The Haley Creek Terrane tectonically overlies rocks of the Valdez Group and has been interpreted as a klippe (Plafker et al, 1985). Rock types in the Haley Creek Terrane include: 1) metamorphosed mafic to intermediate volcanic rocks interlayered with meta-sedimentary units that include metagreywacke and marble; and 2) metamorphosed plutonic rocks that intrude the layered rocks and range composition from gabbro to trondjemite. The layered rocks of the Haley Creek Terrane have been tentatively correlated with the less metamorphosed Strelna Formation east of the Copper River (Plafker et al, 1985).

Wallace (1981) recognized that, with the exception of widespread fault slices of phyllite, all rocks of the Haley Creek Terrane appear to have been metamorphosed originally by an amphibolite facies event. All units were then effected by a complex greenschist event with associated deformation. After a brief discussion of the rock types in the Haley Creek Terrane I will concentrate on this retrograde greenschist event with its associated mylonitic deformation. Specifically, I will discuss the development of a nearly horizontal east-west stretching lineation developed in a steeply dipping east-west striking mylonitic foliation. I will show that the mylonite was produced by deformation in a broad shear zone. I will then present microstructural and mesoscopic observations and quartz c-axis data in an attempt to deduce the sense of shear across the zone.

GEOLOGY

Nine mappable rock units were delineated in the study area. They are described briefly below.

3.1 Tonalite Gneiss (unit tg)

The most abundent rock type within the Haley Creek Terrane is a series of foliated metaplutonic rocks that range in composition from diorite to gabbro, although tonalitic rocks appear to be typical. Euhedral to subhedral hornblende prisms and/or retrograde products of hornblende are in a matrix of plagioclase +/- quartz, the plagioclase has been converted to albite by greenschist facies metamorphism. The rocks are now generally mylonitic gneisses with a strong foliation and/or lineation defined by both a dimensional preferred orientation of remnant igneous minerals as well as new growth of metamorphic chlorite and epidote. The intensity of the structural fabric, however, varies markedly both on a mesoscopic and macroscopic scale. Most mesoscopic fabric variations can be ascribed to either systems of ductile shear zones or variations resulting from lithologic heterogeneity of the package. For example, in some localities relatively leucocratic rocks grade into dark amphibolite gneiss, and in such occurrences an intense low-grade fabric in the tonalite is often absent in the amphibolite. In the latter the only evidence of deformation and retrogression may be hydrothermal alteration along discrete faults. This observation suggests that the mylonitic deformation occurred under brittle-ductile transition conditions with quartz-dominated flow in siliceous rocks and brittle failure in more mafic rocks.

The protolith for the tonalitic gniesses is clearly a series of granitoid plutons that invaded the associated metasedimentary sequence. Evidence for this conclusion include abundant xenoliths within the complex and local irregular contacts, despite the large strains imposed by later deformations.

3.2 Amphibolite Gneiss (unit ag)

Amphibolites are relatively common within the metaplutonic complex (unit tg) but most are too small to map at 1:31680. The amphibolites generally were not strongly reworked during the main retrograde greenschist facies deformation of the Haley Creek Terrane and display the best relict structures from the older deformational history. The amphibolites typically are a medium to coarse grained, moderately foliated, hornblende-plagioclase rock with ubiquitous stringers and pods of trondjemite. As in the tonalite gneisses, the plagioclase is all albite. Other minerals present include sphene, rutile, apatite, and locally epidote. Trondjemite stringers within the amphibolite typically are tightly folded and locally display ptygmatic fold styles. This observation suggests that the trondjemites were either derived by melting of the gneiss or were emplaced as igneous bodies when the gneiss was at high temperatures and was very ductile. Although younger deformation has smeared contact relationships the amphibolites appear to predate the main igneous suite of the metaplutonic complex. In some places, foliated or unfoliated amphibolites have been intruded by or are contained as xenoliths in the tonalite gneisses. It is not totally clear from field relationships, however, if the amphibolites represent a country rock for the metaplutonic rock or were emplaced as plutons of the igneous suite.

3.3 Ultramafics and Gabbro (unit um)

An occurrence of ultramafic and gabbroic rock was recognized along a northwest trending shear zone in the west-central portion of the Haley Creek Terrane. The rock is only exposed on cliff faces and its contact relationship with adjacent units as well as internal geometry are uncertain. Rocks observed in talus derived from the unit include three rock types: 1) a coarse-grained hornblendite composed of 90-100% light green hornblende crystals up to 3cm in length and a white groundmass of zoisite; 2) a coarse-grained, dark, hornblende gabbro and hornblendite in which large (1-3cm) black hornblende crystals comprise 60-90% of the rock and the remainder is comprised of altered plagioclase; and 3) a schistose rock containing chlorite + serpentine +/- amphibole.

3.4 Marble (unit m)

Marble occurs as consipicous bands and pods throughout the Haley Creek Terrane and forms one of the most important marker units within the terrane. The rock varies from white to black, although a light grey rock with alternating thin (1mm-1cm) dark and light bands is typical. In some rocks the dark bands appear to be due to the presence of graphite, although generally the bands are marked by calc-silicate layers. Assemblages are carbonate + quartz + white mica +/- chlorite +/- actinolite +/- epidote +/- sphene and locally diopside. The marble typically occurs in association with quartz- rich mica schists (unit qms) but the rocks also contact metaplutonic rocks and occur as structural pods within phyllite units. The latter could indicate that the marbles are derived from a protolith of two different ages but the contact relations are too ambiguous to allow a firm conclusion.

Structurally the marbles show consipicuous evidence of large ductile strains including a strong L or LS tectonite fabric, ubiquitous small scale isoclinal folds in layering, and a complex map pattern suggestive of polyphase folding and (or) sheath folding.

3.5 Quartz-Rich Mica Schists (unit qms)

This unit is , in part, a composite metasedimentary unit containing a variety of rock types including lenses of marble and quartzo-feldspathic schist that are too small to map at 1:31680. The unit is characterized, however, by dominance of a rock in which thin (1mm-1cm) quartzite layers are laminated with quartz-rich chlorite- muscovite schist. On fresh surfaces the quartzite is white to medium grey and the pelitic layers are grey to dark brown. The rock as a unit, however, generally weathers to a reddish brown or red color, apparently due to the presence of disseminated pyrite in the rock. In the quartz-rich schists the pyrite is probably a primary sedimentary feature but iron staining due to hydrothermal alteration along faults is also present in the area and can be easily confused with mica schists in cliff face exposures.

The protolith for the unit is uncertain but rythmic lamination suggests bedded chert and argillite. Layering is generally mesoscopically folded into tight isoclinal folds with axial planes parallel to the mylonitic schistosity and axes sub-parallel to lineation. The folded layering, however, can locally be seen to parallel an older metamorphic fabric that, at least locally, was associated with growth of coarse biotite (now largely converted to chlorite).

3.6 Quartzo-Feldspathic Schist (unit qfs)

One of the more extensive units of the Haley Creek Terrane is a group of light brown to greenish brown, chloritic, quartzo-feldspathic schists. The rock typically shows only subtle, large-scale lithologic layering within the unit with individual layers varying from a few centimeters to a meter in thickness. Quartz segregations locally parallel layering within the unit but are not necessarily diagnostic of the unit.

The protolith for the unit, where mapped, is thought to be two very different rock types: 1) a quartzo-feldspathic sedimentary rock, probably a quartz-rich greywacke sequence; and 2) some highly deformed metaplutonic rocks. Evidence for a sedimentary protolith includes the subtle layering within the unit and common interlayering of the unit with quartz-rich mica schists (unit qms), a clearly metasedimentary unit. Evidence for a plutonic protolith includes the fact that tectonites developed in high strain zones within the metaplutonic complex are similar quartzo-feldspathic schists. Often schistose metaplutonic rocks could be recognized by the presence of low strain pods with remnant igneous minerals and were mapped separately as unit tg.

3.7 Trondjemite Gneiss (unit tr)

Pods and stringers of leucocratic schist and gneiss are ubiquitous in all rocks of the Haley Creek Terrane with the exception of phyllite. Most of the bodies are too small to show at 1:31680. The rocks themselves are a uniformly white, generally strongly foliated and/or lineated rock in which plagioclase makes up between 75 and 90 percent of the rock and quartz constitutes 10-25%. Some of the rocks contain no obvious mafic minerals but most contain 5-10% muscovite, epidote and/or chlorite.

All primary textures have been strongly modified by foliation development and recrystallization. As a result, most of the trondjemite bodies are strongly flattened into foliation and form pods and lenses aligned with foliation and lineation. In low strain zones, however, the trondjemites clearly occur as cross-cutting dikes and sills invading other rocks of the Haley Creek Terrane.

3.8 Phyllite (unit p)

Small structural slabs of phyllite are common in the northern half of the Haley Creek Terrane. The rock is generally medium grey to black phyllite with thin quartz segregations developed parallel to foliation. The rock characteristically contains a strong phyllitic cleavage cut by a pronounced second phase crenulation cleavage developed at a high angle to layering. The phyllite clearly is younger than the associated Haley Creek Terrane schists because it is nowhere invaded by the trondjemite dikes and sills that characteristically invade the schists. Many of the phyllites are in brittle fault contact with adjacent rocks or occur along major faults. Elsewhere, however, the contacts appear to be ductile shear zones. The phyllites may correlate with the Valdez Group but this correlation cannot be easily reconciled with available isotopic ages.

3.9 Valdez Group (unit V)

The Haley Creek Terrane is in fault contact with the Valdez Group. Where it is exposed, the contact between the Haley Creek Terrane and the Valdez Group is sharp. In the map area the Valdez Group is comprised of phyllites, slates and metasandstones with phyllite as the predominent rock type. Foliation is marked by strong phyllitic cleavage and by compositional lamination. The main foliation has been crenulated and a steeply southdipping crenulation cleavage has formed locally. Second phase folds are present at several scales and range from tight to open. Where examined in the study area, the Valdez Group shows no evidence of having undergone the intense mylonitic deformation that is characteristic of rocks in the Haley Creek Terrane.

MYLONITIC DEFORMATION

4.1 Background

In a recent paper by Lister and Snoke(1984, p.617) they state that although there are many aspects which need to be considered in the definition of a mylonite they tend to have two important properties, (a) they are usually rocks which mark the locus of a zone of intense non-coaxial deformation; and (b) during flow the matrix minerals of a mylonite (e.g. quartz) deform crystal plastically. Two effects result with the accommodation of large strains by the matrix minerals: (a) extensive dynamic recrystalization with a resulting reduction in grain size; and (b) development of strong crystallographic preferred orientation patterns. Cataclastic processes are also involved in mylonitization. For example, minerals other than the matrix minerals, such as feldspar, may deform in a brittle fashion. Both of these effects are clearly illustrated in rocks from the Haley Creek Terrane (figure 4-1).

There are numerous unanswered questions concerning the type of flow involved in the production of a mylonite. These questions result from problems in determining both the type of flow involved and the relative importance of pure shear vs. simple shear in a specific shear zone. Lister and Snoke (1984, p.618) summarize the problem as follows; (a) mylonites which form by strictly coaxial deformation are scarce and, (b) in many cases where it has been argued that flattening has been involved in the production of mylonite, detailed fabric and microstructural studies have revealed evidence for a zone of non-coaxial laminar flow. (c) although it is theoretically possible to arrive at the bulk movement picture by detailed analysis of the variation of the mesoscopic

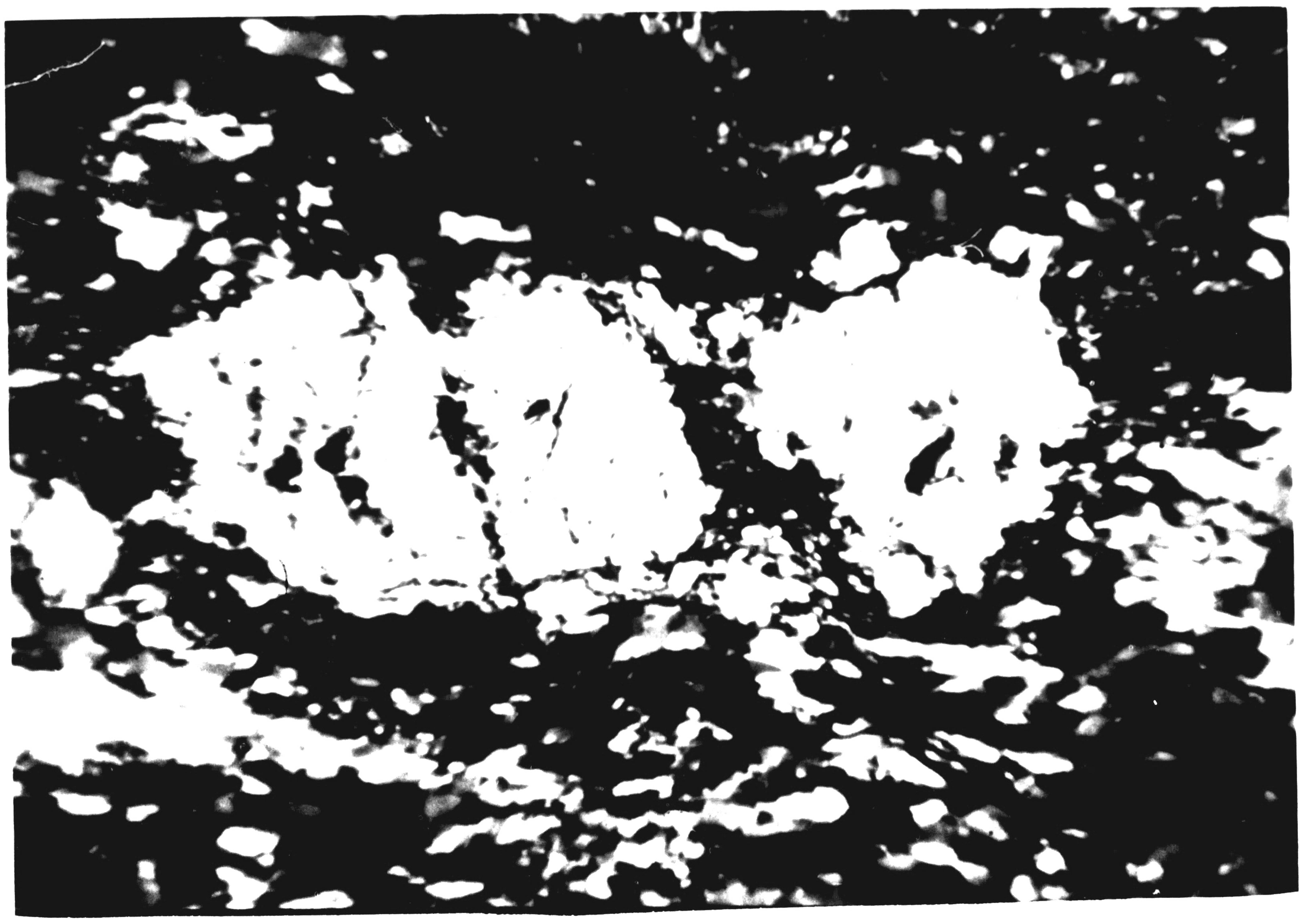


Figure 4-1: Photomicrograph showing crystal plastic deformation of the matrix mineral (quartz) of a mylonite from the Haley Creek Terrane. The specimen also exhibits brittle deformation of a feldspar crystal.

movement picture problems are encountered when this is attempted in practice. Major shear zones commonly anastomose, in which case the large-scale movement picture is defined by a composite of movement zones which separate lenses of less deformed rock.

4.2 Mesoscopic Structure in the Haley Creek Terrane

Foliation development: A mylonitic foliation is the most strongly developed planer fabric in the Haley Creek Terrane. This foliation typically strikes east-west and is steeply dipping (figure 4-2). However, the degree to which the foliation is developed varies areally. Where the foliation is strongest it is often impossible to distinguish if any other structures were present whereas in other areas the fabric clearly overprints an older, amphibolite facies fabric (Wallace, 1981). The mylonitic foliation commonly parallels lithologic contacts. This parallelism can be seen in a detailed map of the area (plate 1) in which many of the units trend east-west. All contacts have been tectonically modified, although it is not possible to determine the magnitude of the displacements on these contacts.

Folding: Folds associated with the mylonitic deformation event are very tight to isoclinal and the mylonitic foliation is axial planar to the folds. A plot of fold axes, figure 4-3, shows that they trend east-west. Where developed in the marbles, folds related to the deformation are disharmonic (figure 4-4).

Boudinage: A characteristic feature of the mylonitic deformation was the production of lenses of material at all scales. However, there is not always a lithologic contrast between lenses and matrix. Where the lenses and matrix did differ in composition, the lens was not always the more competent unit. Hence many of the lenses are probably fault slices, though at least some are large

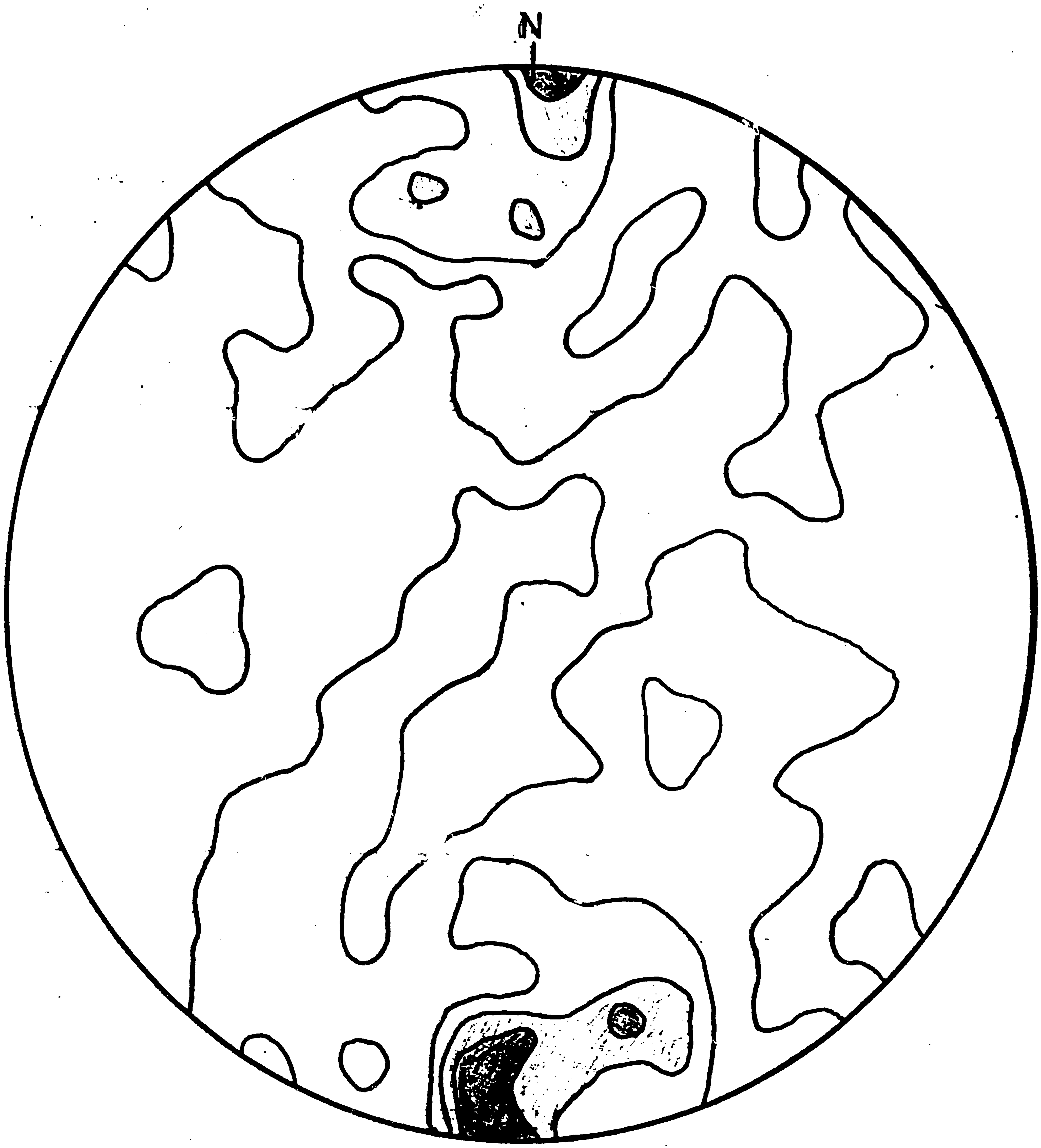


Figure 4-2: Plot of poles to foliations showing a dominant east-west strike and steep dip.

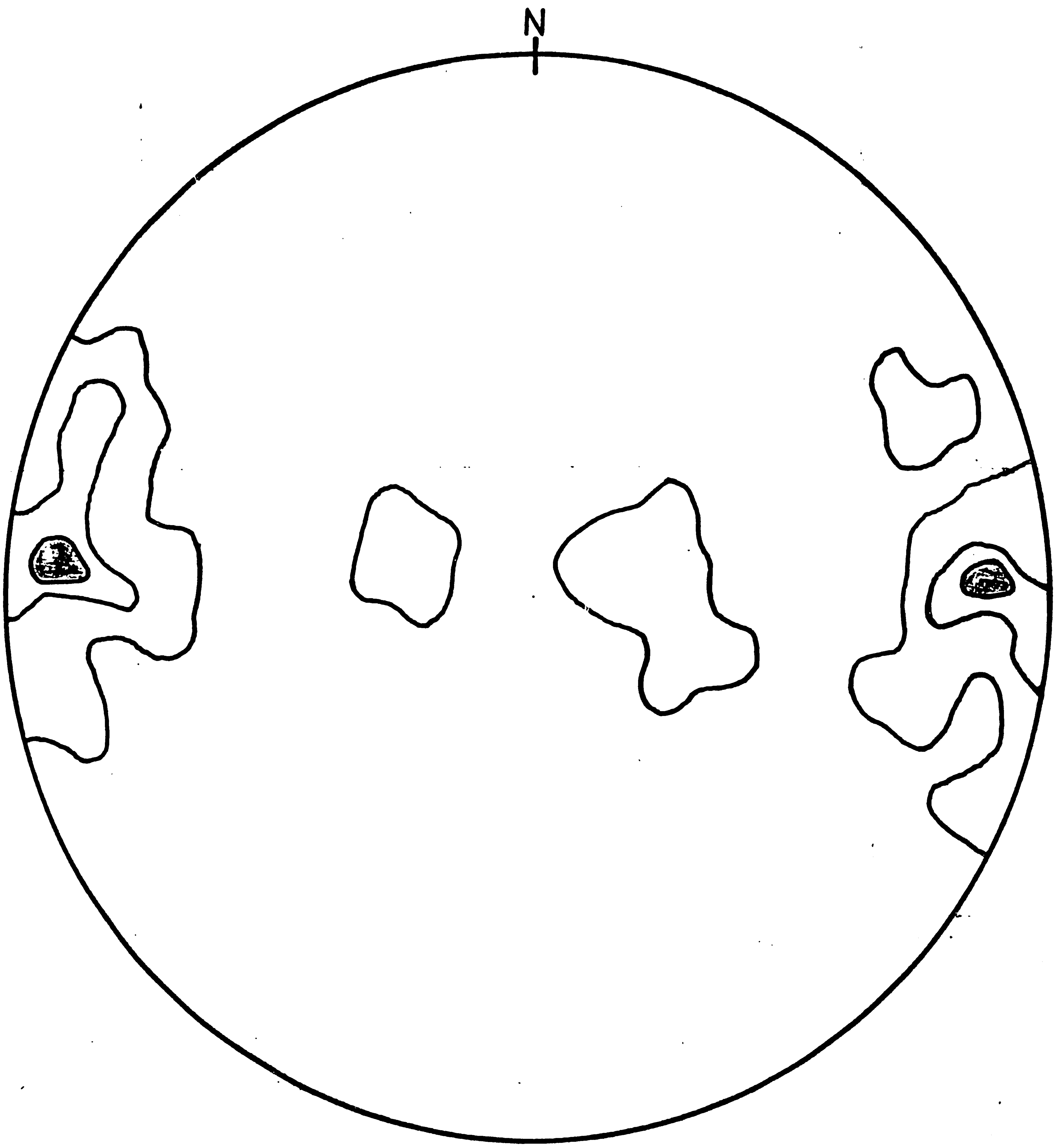


Figure 4-3: Plot of fold axes related to the mylonitic deformation event.

Figure 4-4: Disharmonic folding exhibited by marbles from the Haley Creek Terrane.

boudins (Wallace, 1981 p.153). The lenses generally lie within the foliation plane and are oriented with their long axes down dip and their intermediate axes east-west. Hence I conclude that they record extension in an east-west direction. On a smaller scale, layers more competent than the rocks surrounding them are boudinaged. This feature is often shown by leucocratic dikes (figure 4-5). Again, the boudins have their intermediate axes parallel to the strike of the east-west foliation.

Evidence for East-West Stretching: Along with the presence of boudins there are other lines of evidence, mesoscopic and microscopic, that the mylonites record a deformation in which east-west extension was a key component. Because previous studies have not made this kinematic interpretation (e.g. Wallace 1981, 1984, 1985 and Plafker et al, 1985) it is important to document the evidence for this conclusion.

A pervasive east-west lineation (figure 4-6), defined by mineral grains and aggregates of minerals including quartz, calcite, hornblende, and feldspar, is present in outcrop and thin- section scales. Many of the rocks in the Haley Creek Terrane are in fact L-tectonites although elsewhere in the area the lineation is only poorly developed indicating variations in strain. This horizontal, east-west lineation is the characteristic fabric element in the Haley Creek Terrane and is here interpreted to be a stretching lineation. Evidence for this conclusion include the following: 1) In some calcareous units an L-tectonite fabric is marked by rods of calcite grains, an observation implying that the lineation is a shape fabric; 2) The lineation is also often well developed in metaplutonic rocks of the Haley Creek Terrane (figure 4-7). On a microscopic scale, sections cut parallel to lineation and perpendicular to foliation show older,

Figure 4-5: Leucocratic dikes boudinaged with their intermediate axes parallel to the strike of the east-west foliation.

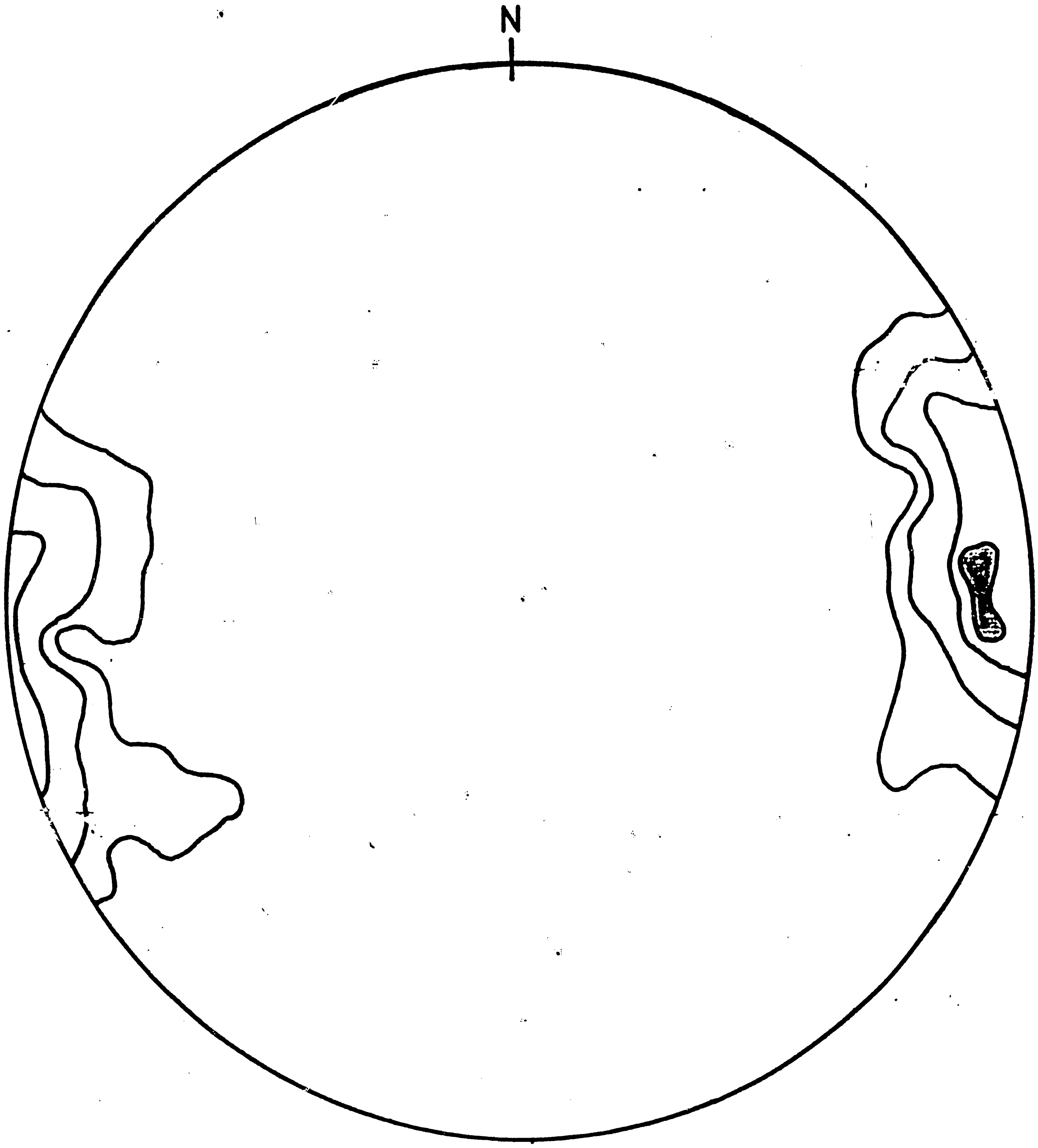


Figure 4-6: Plot of lineations showing a dominant east-west trend and shallow plunge.

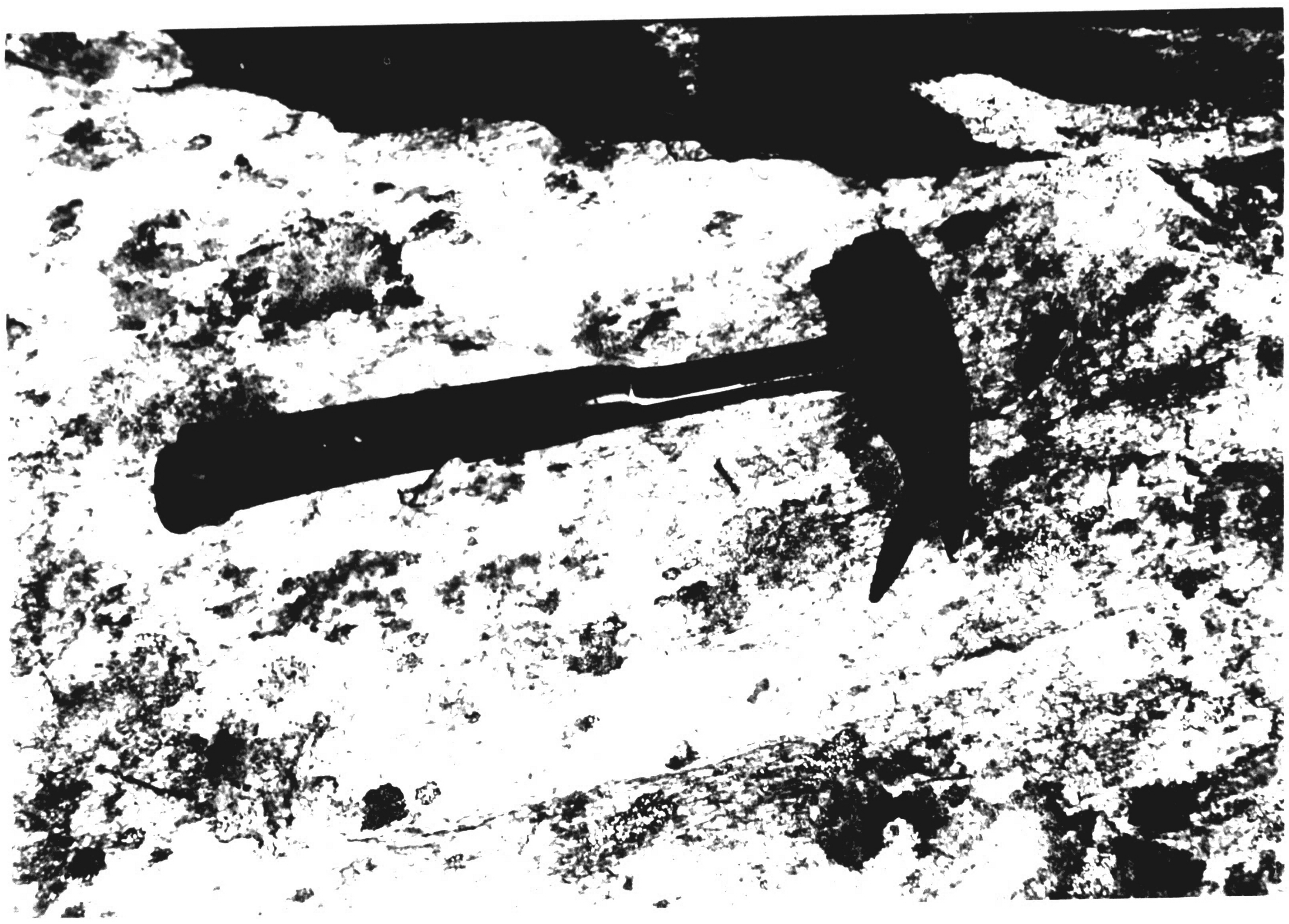


Figure 4-7: Lineation as seen in an outcrop of tonalite gneiss in the Haley Creek Terrane.

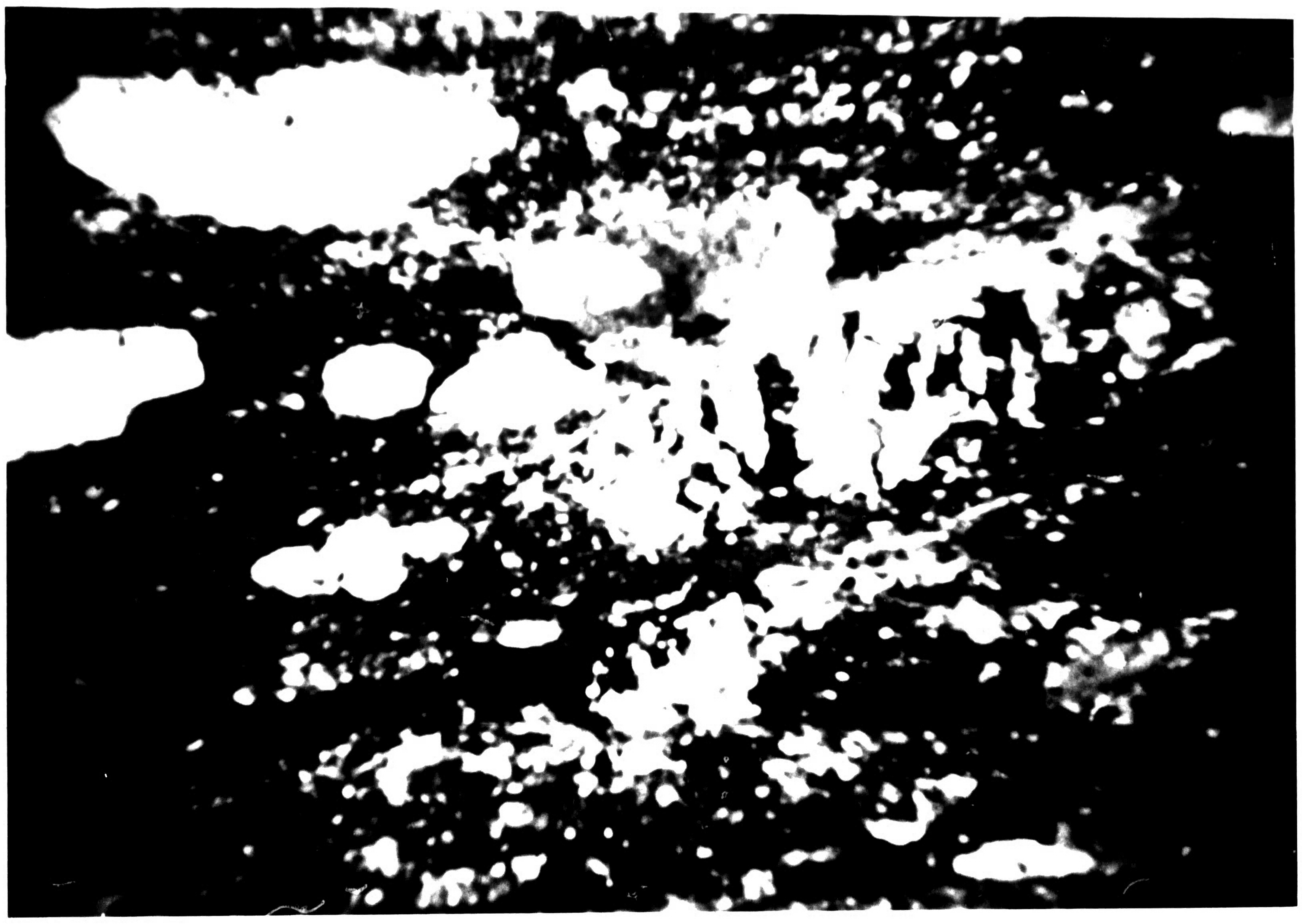


Figure 4-8: Photomicrograph of lineation in a calcareous unit defined by rods of calcite grains. The photomicrograph also shows a brittlely deformed hornblende grain with the space between separating fragments infilled with a fiberous mineral (chlorite).

amphibolite facies mineral grains strung out along the lineation (figure 4-8).

3) Fiborous extensional veins were seen in a number of localities in the Haley Creek Terrane. These crack-like discontinuities formed at a high angle to the lineation and are infilled with fiberous quartz, zoisite, calcite, and/or chlorite (figures 4-9 and 4-10). This type of mineral fiber development is thought to be a crack-seal process developed during stretching increments and the fibers link points that were once in contact. Thus they give the displacement vector across the vein (Ramsey and Huber, 1983). In the Haley Creek Terrane these mineral fibers are parallel to the main phase lineation.

4) In a few areas mesoscopic rodding structure was seen. The best examples were seen in metasedimentary units (figures 4-11). This type of structure is commonly associated with strain in which the long axis of the strain ellipsoid (stretching direction) parallels the long axis of the rods (Ramsey and Huber, 1983). In the study area the long axes of these rods parallel the lineation.

5) Ductile shear zones indicating strike-slip offsets are clearly developed within low-strain areas of metaplutonic rocks(figure 4-12). In these zones, east-west lineations lie within the shear zone foliation, i.e. parallel to the regional lineation trend.

4.3 Kinematic Interpretation

I believe the observations above leave little doubt that the pronounced horizontal lineation developed in a east-west, steeply-dipping foliation records a main deformation in which a north-south shortening was accompanied by pronounced east-west extension. The association between this fabric and mesoscopic ductile shear zones implies that this deformation was produced in a

Figure 4-9: Extensional vein infilled with fiberous chlorite.

Figure 4-10: Extensional vein infilled with fiberous quartz and zoisite. The quartz is optically continuous across the vein.

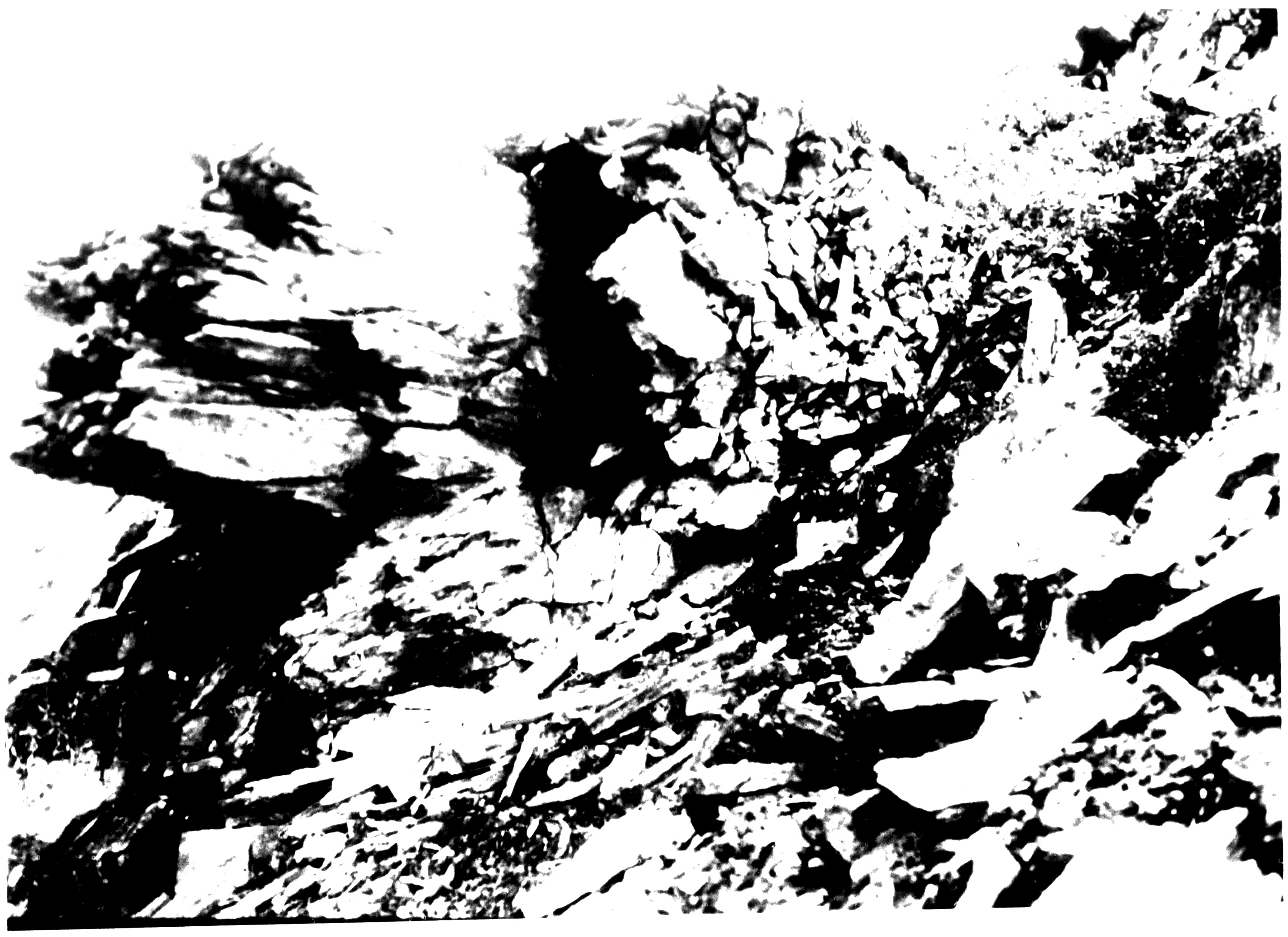


Figure 4-11: Rodding structure developed in an outcrop of quartz-rich mica schist from the Haley Creek Terrane.

broad zone dominated by simple shear. Microscopic observations presented below clearly support this conclusion that the fabric is the product of non-coaxial strain.

4.4 Sense of Shear

The Haley Creek Terrane is typical of wide shear zones and mylonitic belts in that it is not possible to find the boundaries of the belt, and offset marker horizons are not obvious. Without offset marker horizons other criteria such as s-c relationships, rotated porphyroclasts or quartz c-axis data must be used (Simpson and Schmid, 1983). These criteria, when applied to Haley Creek Terrane mylonites, suggest deformation in a broad zone of dextral shear.

Ductile shear zones: In areas of low strain throughout the Haley Creek Terrane, metaplutonic rocks are cut by ductile shear zones (figures 4-12). these shear zones generally show dextral movement, although locally the shear zones form conjugate sets. The latter presumably reflects a local flattening within a broad shear system.

S-c relationships: Planar anistropies (c and s surfaces) were observed in the field and in thin section. The s surfaces of these ductile shear zones are oriented at a high angle to the c surfaces and curve into the c surfaces so that the angular relationships between the two surfaces indicate the sense of shear in the rock. The c surfaces are initiated and remain parallel to the main shear zone boundry with progressive deformation and they are considered to be spaced slip surfaces with a sense of shear the same as that of the overall shear zone (Simpson and Schmid,1983 p.1284)

On a mesoscopic scale, s-c relationships were seen at several localities, typically associated with lithologic heterogeneities (e.g. figure 4-13). On a

Figure 4-12: Ductile shear zones cutting low-strain metaplutonic rock from the Haley Creek Terrane. Asymmetry indicates a dextral sense of shear.

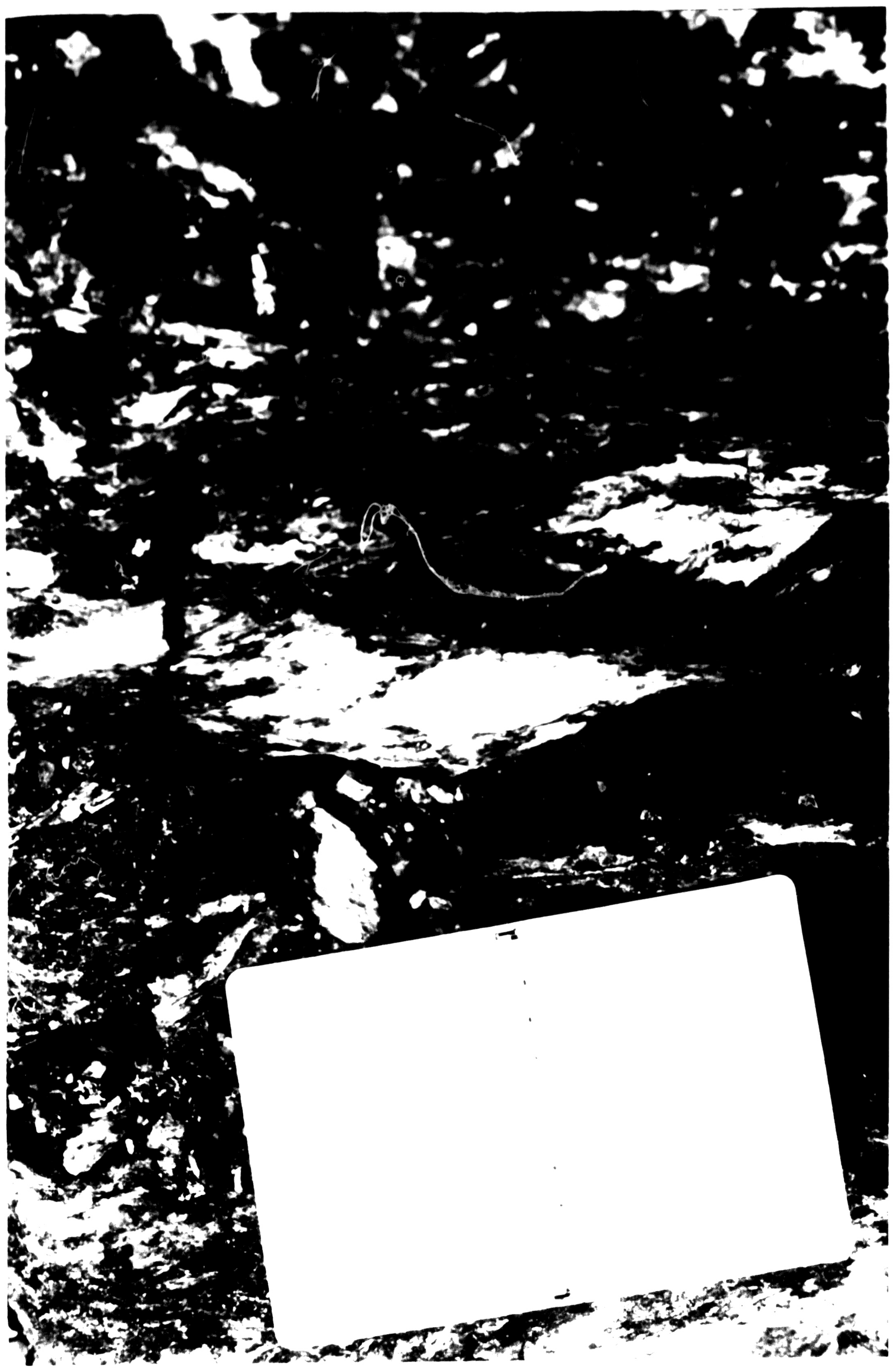


Figure 4-13: Metaplutonic rock from the Haley Creek Terrane showing high-strain zones (c-bands) separated by lower strain flattening planes (s-bands). Anisotropy indicates dextral shear.

microscopic scale, s-c fabrics are common (e.g. figure 4-14). Microstructurally the c-surfaces appear as thin layers of a recrystallized polymineral aggregate with a reduced grain size.

Rotated Porphyroclasts: Within many shear belts mylonitic gneisses occur that contain larger and relatively flow-resistant porphyroclasts. Foliation planes are asymmetrically distributed around the porphyroclast so that the grains have a retort shape with tails of finer-grained recrystallized material of the same composition as the porphyroclast extending along the foliation plane in the direction of shear (Simpson and Schmid,1983 p.1281). These retort-shaped crystals have been used to deduce the sense of shear in foliated rocks. The fine-grained material within the tails is usually the product of dynamic recrystallization. In a shearing environment the weaker material within the tails has a higher rate of rotation into parallelism with the overall foliation of the rock, whereas the less deformable porphyroclasts rotate more slowly so that their long axes remain oblique to the foliation in the surrounding matrix (Simpson and Schmid, 1983 p.1282). Rotated porphyroclasts observed in the Haley Creek Terrane indicate a general pattern of dextral shear.

Where a high ductility contrast occurs between a rotated grain and its matrix within a foliated rock it is generally possible to ascertain the sense of rotation of the grain and hence, the shear sense. Observations of the overall symmetry of the pressure shadows with respect to the porphyroclast and foliation must be considered when deducing the sense of rotation and thus shear(Simpson and Schmid,1983 p.1282). This type of relationship was seen in a number of thin-sections of Haley Creek Terrane rocks. Generally feldspar or garnet (figure 4-15) were the rotated porphyroclasts. The garnet in figure 4-15

Figure 4-14: Photomicrograph of a tonalite gneiss from the Haley Creek Terrane showing s-c band relationships indicative of a dextral sense of shear.

shows a dextral sense of shear (clockwise rotation) as did the majority of the markers from the Haley creek Terrane.

<u>Quartz c-axis fabrics</u>: Quartz c-axis fabrics were measured in a number of the mylonites discussed here. The sense of shear was not always clear although the fabric asymmetry of the plots clearly indicates a zone of non-coaxial flow. The pattern of preferred orientation varied in the five specimens measured. Three show slightly asymmetric plots indicating a component of non-coaxial shear (figures 4-16A, B, and C), and two specimens (figures 4-16D and E) show a strong pattern of preferred orientation asymmetric with respect to the principal axes of finite strain. I interpret figures 4-16D and 4-16E as indicating dextral movement; figure 4-16E with a possible coaxial overprint. The nearly horizontal stretching lineation is developed in the mylonitic foliation; the orientation of the foliation has been plotted of the figures.

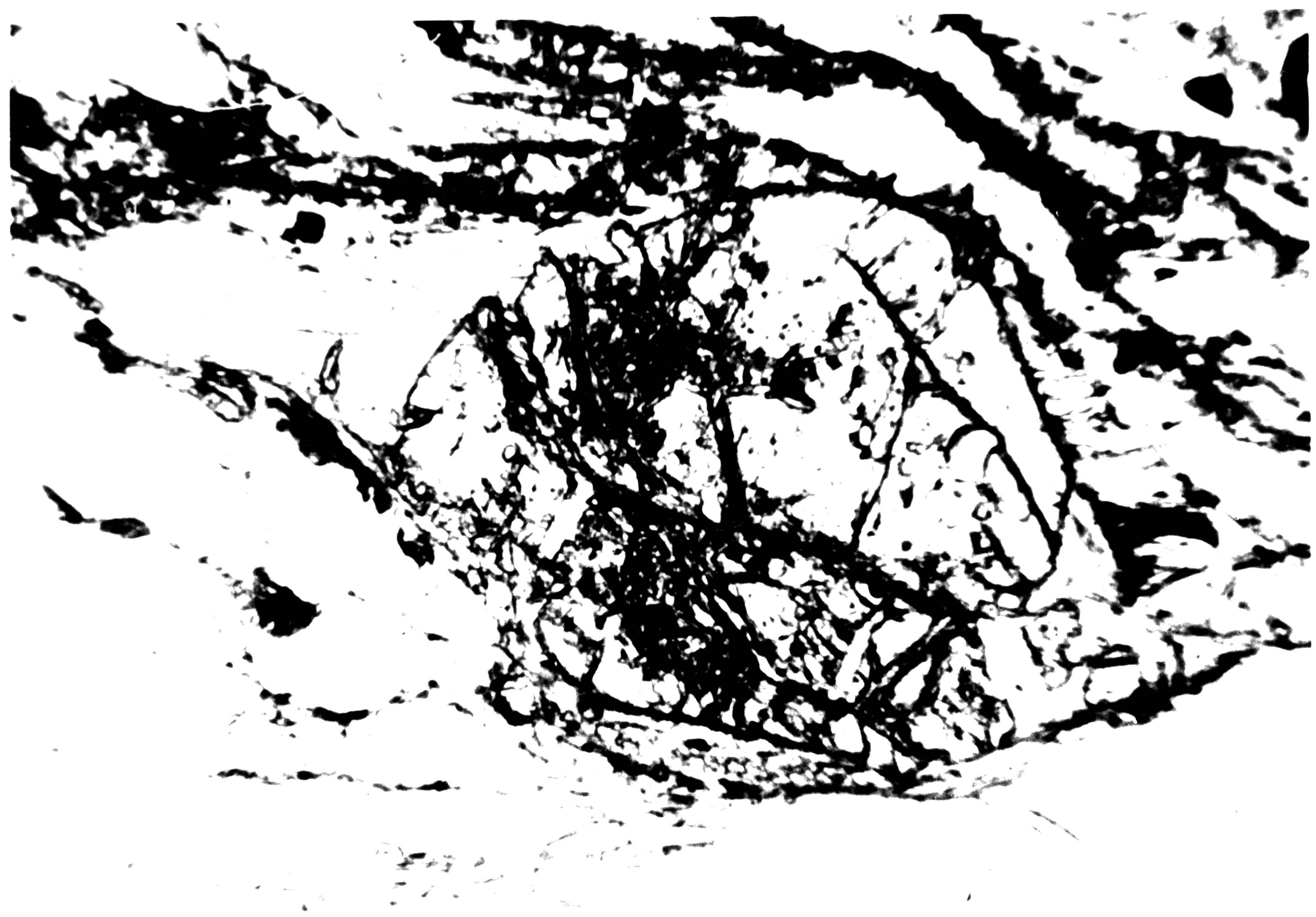


Figure 4-15: Photomicrograph showing pressure shadows around a garnet crystal. Symmetry of the pressure shadows is interpreted to indicate a dextral sense of shear (clockwise rotation).

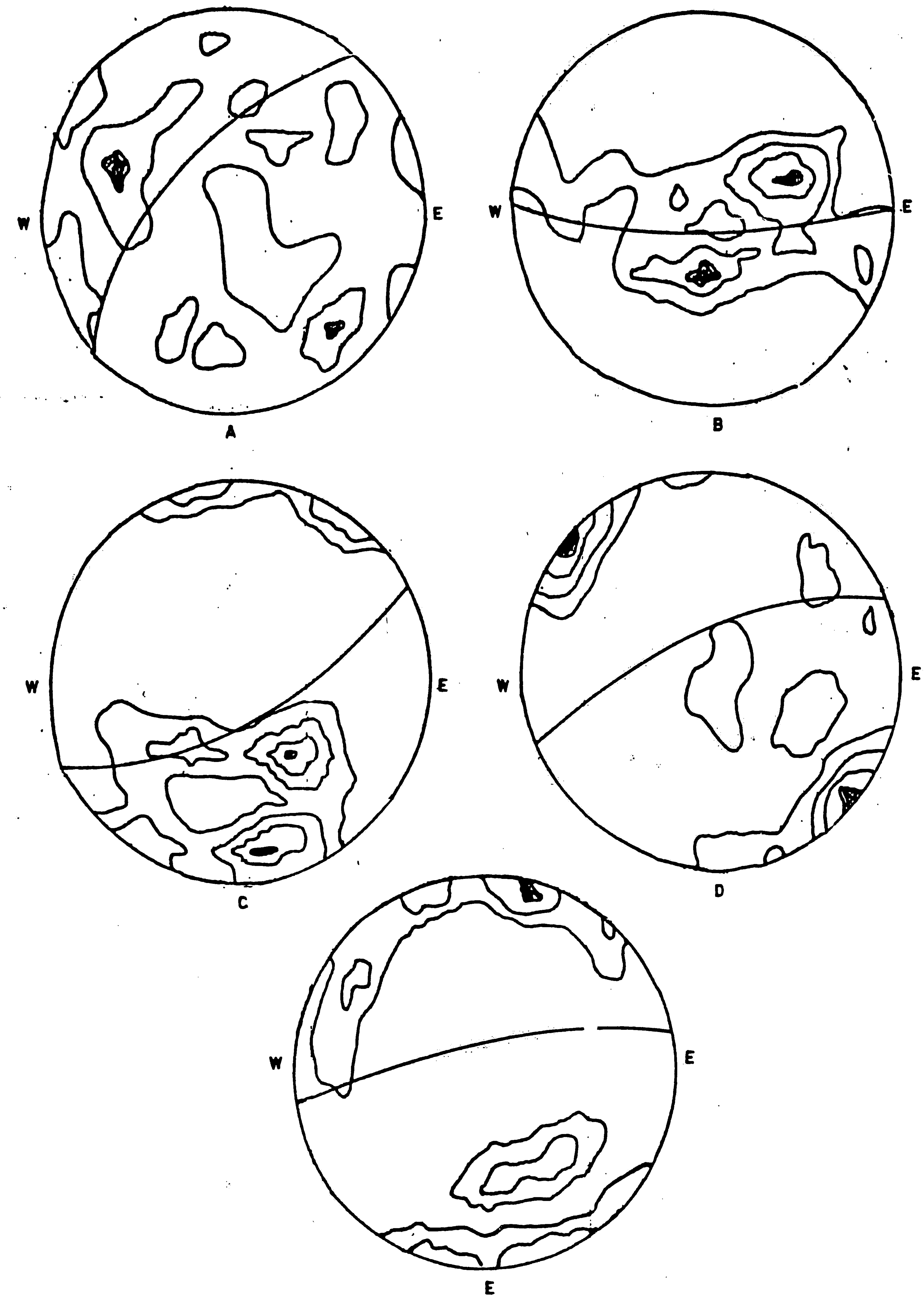


Figure 4-16: Quartz c-axis fabrics from quartz-rich mica schists in the Haley Creek Terrane. Fabric asymmetry in A, B, and C indicates a component of non-coaxial shear. The strong patterns of preferred orientation in D and E indicate dextral movement; E with a possible coaxial overprint.

DISCUSSION AND CONCLUSIONS

Age of the strike slip event: Although the absoulute ages need to be clarified, the microstructural work carried out so far in conjunction with the mesoscopic observations indicate that the retrograde mylonitic deformation in the Haley Creek Terrane represents a broad zone of ductile dextral shearing. The age of this deformation needs further clarification through more sophisticated geochronology. Nonetheless, available ages (Winkler et al, 1981) strongly suggest a late Mesozoic, probably Early Cretaceous, age for the event.

Nearly all of the ages available are K-Ar ages. Winkler et al (1981) reports four K-Ar ages of hornblende in metaplutonic rocks that range from 148 m.y. (Late Jurassic) to 122 m.y. (Early Cretaceous) and two K-Ar ages on biotite and muscovite from the enclosing schistose rocks of 123 m.y. and 110 m.y. The K-Ar ages may only be partially reset and therefore meaningless as age indicators of the deformation event or, they may record slow cooling following the retrograde greenschist event. The most viable interpretation of the data, if it is to be incorporated into a discussion of the metamorphic and structural evolution of the Haley Creek Terrane, is to consider the biotite and muscovite K-Ar ages as minimum ages for the shearing event. The reasoning behind this interpretation is that argon seems to be quantitatively retained in biotite below about 260 C and in muscovite below about 320 C (Harrison and McDougall, 1980,1981), whereas mineralogical associations derived from the greenschist facies metamorphism at the time of deformation indicate temperatures on the order of 400 C; considerably above biotite and muscovite stability. The hornblende ages have been ignored because of the greater Ar retention by hornblende; hornblende is thought to have a closure temperature in the range of 480 to 500 C (Harrison, 1981).

A maximum age for the shearing is implied by U-Pb ages on the tonalite gniesses of approximately 145 m.y. (Plafker, personnel communication to Pavlis, 1985). Another line of evidence concerning the maximum age of the mylonitic deformation event comes from trondjemite bodies found throughout the terrane. The age of the trondjemites in the Haley Creek Terrane, which have undergone mylonitic deformation, is uncertain but they are lithologically similar to and can be tentatively correlated with trondjemites in the western Chugach Mountains (Pavlis, 1982). This observation is important because the trondjemites of the western Chugach intrude the McHugh Complex and a K-Ar age on hornblende from these trondjemites gives an age of 124 +/- 8 (Pavlis, 1982); a relationship that implies that the younger K-Ar ages from the Haley Creek Terrane are good indicatois of the age of shearing, that is post 124 m.y. and pre 110 m.y.

Allowable tectonic scenarios: Most of the available radiometric ages are K-Ar ages which are easily partially or totally reset. This problem is not easily evaluated; the scatter in ages may reflect variations in thermal conditions in the terrane and thus be dependent upon locality. The age problem forces two scenarios to be considered: 1) mylonitic deformation along a dextral strike slip system prior to the emplacement of the McHugh Complex and; 2) mylonitic deformation after the emplacement of the McHugh.

If the deformation predates the McHugh Complex (figure 5-1), the sequence could be: 1) emplacement of the Haley Creek Terrane by right lateral wrench faulting along the southern Alaska margin with corresponding mylonitic deformation, 2) underplating of the sequence by the McHugh Complex during subduction along the southern edge of the Wrangellia-Peninsular-Alexander composite terrane, 3) emplacement of flysch (Valdez Group) during continued subduction (Pavlis, 1982) and, 4) emplacement of the Haley Creek Terrane to its present position as a klippe along a folded thrust. If the deformation postdates emplacement of the McHugh Complex (figure 5-2) the sequence would be: 1) emplacement of the McHugh Complex, 2) emplacement of the Haley Creek Terrane along a right lateral wrench fault, 3) emplacement of the Valdez Group and emplacement of the Haley Creek Terrane as a klippe along a folded thrust.

There are a number of arguments which support the post McHugh sequence making it the preferred scenario. The trondjemites of the western Chugach Mountains, which appear to correlate with the deformed trondjemites of the Haley Creek Terrane, intrude the McHugh Complex. Also, there is a simularity in the deformational style between the Haley Creek Terrane and deformation of the McHugh Complex in a slab just north of the Haley Creek Terrane. In fact the slab is sufficiantly different from "typical" McHugh that Winkler et al (1981) mapped it as a separate terrane, the Bernard Creek Terrane, and, in the first paper released by the TACT group (Plafker et al, 1985), the McHugh Complex north of the Haley Creek Terrane was mapped as Haley Creek Terrane. It is possible to speculate, based on the similarity of deformational style between the two areas, that some of the quartzo-feldspathic schists recognized in the Haley Creek Terrane may have been derived from the McHugh Complex.

Regional significance: The possible importance of strike slip motion in altering the original distribution of tectonic elements in south-central Alaska should not be underestimated. It has long been recognized that major strike

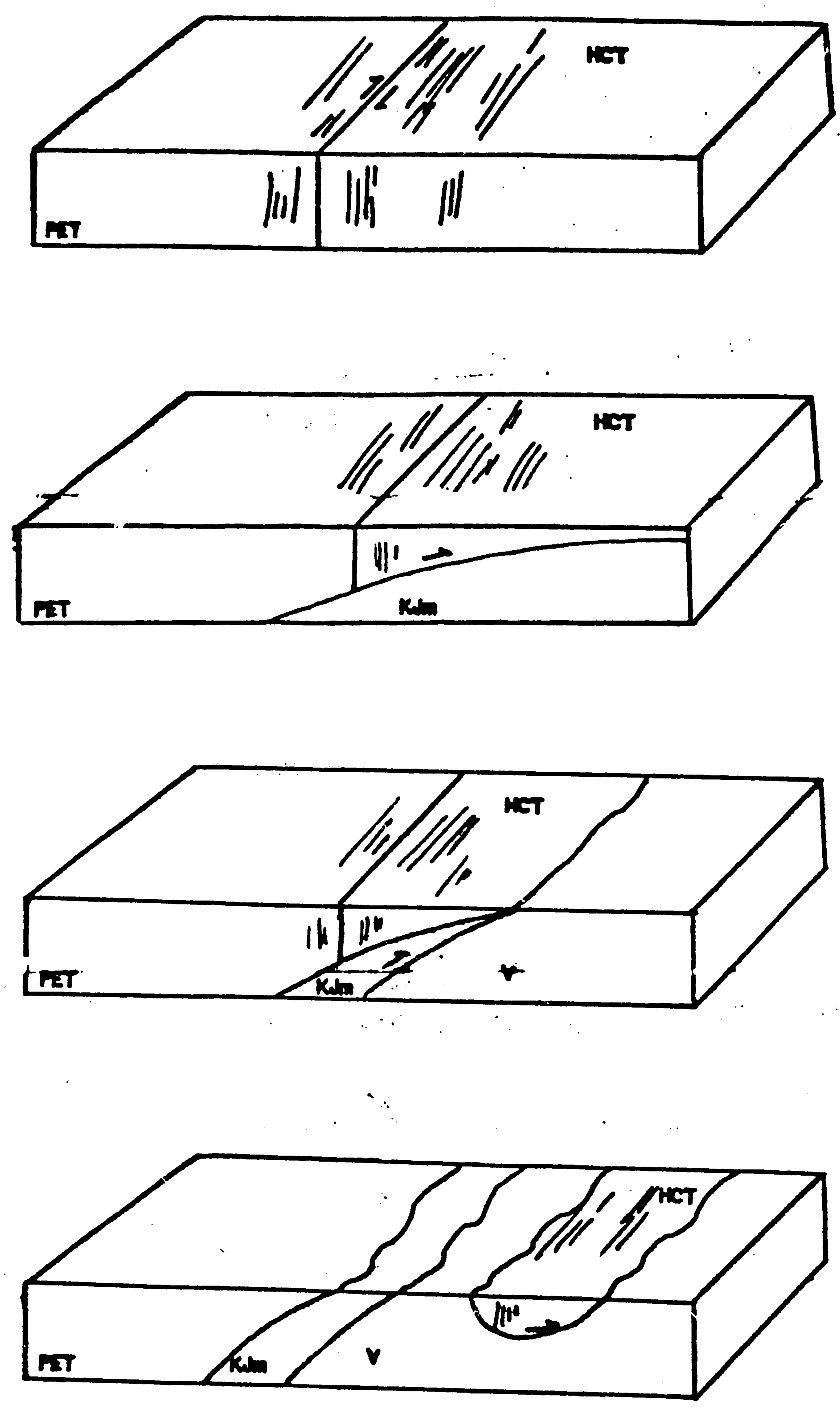


Figure 5-1: Possible sequence of events if the mylonitic deformation predates emplacement of the McHugh Complex. See text for discussion.

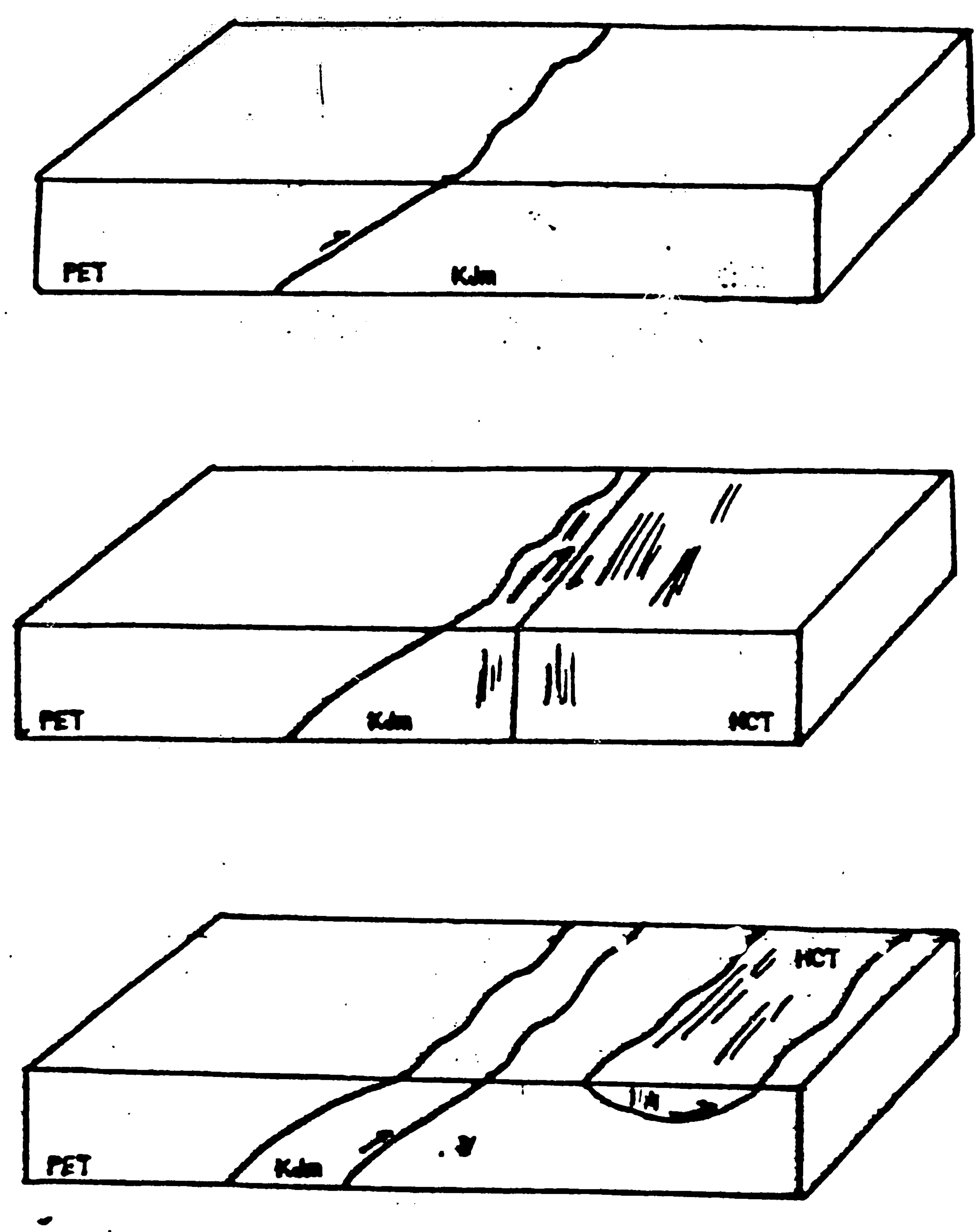


Figure 5-2: Possible sequence of events if the mylonitic deformation postdates emplacement of the McHugh Complex. See text for discussion.

slip faulting has occurred in southern Alaska. Right lateral, strike slip has also been suggested in south-central Alaska (Grantz, 1964,1966; Fuchs, 1980; Pavlis, 1982; and Moore et al, 1983) but seldom substantiated. The recognition here that the mylonitic deformation in the Haley Creek Terrane is a result of right lateral strike slip motion in south-central Alaska is therefore one of the first clear indicators of the process.

The magnitude of displacement on the dextral shear zone indicated by the Haley Creek Terrane is unknown. There are a number of possibilities for the place of origin of the Haley Creek Terrane; the key lies in correlating rock units. Correlation of the Haley Creek Terrane with the Strelna Formation has been suggested by Plafker et al (1985). Presently the Haley Creek Terrane lies south of the Peninsular Terrane while the Strelna Formation lies east of the Copper River (figure 1-1), thus a correlation between the two would require displacement on the order of 40 to 50 kilometers.

Because a correlation of the Haley Creek Terrane with the Strelna Formation is uncertain it is important to consider other possible correlations. Wallace (1981, p.220) speculates on the possible correlation of the Haley Creek Terrane with rocks of the Alexander Terrane. Pavlis (1982) noted a large offset of Early Cretaceous McHugh Complex relative to its apparently coevial arc, the Gravina-Nutzotin belt. These observations, taken together, suggest a displacement on the order of 400 kilometers.

Obviously, more work is needed in order to determine the amount of offset. More detailed studies on possible correlatives of the Haley Creek Terrane are required. Paleomagnetic work might also be helpful in determining the amount of offset along the dextral shear zone that is indicated by the mylonitic deformation of the Haley Creek Terrane.

REFERENCES

Bell, T.H., and Hammond, R.L., 1984, On the internal geometry of mylonite zones: Journal of Geology, v.92, p.667-686.

Berg, H.C., Jones, D.L., and Richter, D.S., 1972, Gravina Nutzotin belt-Tectonic significance of an upper Mesozoic sedimentary and volcanic sequence in southern and southeastern Alaska: U.S. Geol. Surv., Geol. Rep., 55, 7-9.

Borradaile, G.S., Bayly, M.B., and Powell, C.McA., editors, 1982, Atlas of Deformational and Metamorphic Rock Fabrics. Springer-Verlag, Berlin, Heidelberg, New York, 551p.

Burns, L.E., 1985, The Border Ranges ultramafic and mafic complex, south-central Alaska: cumulate fractionates of island arc volcanics: Canadian Journal of Earth Sciences, v.22, no.7, p.1020-1038.

Burns, LE., Little, T.A., Newberry, R.J., and Pessel, G.H., 1983, Preliminary geologic map of parts of the Anchorage C-2, C-3, D-2, and D-3 Quadrangles, Alaska: Alaska Div. of Geol. and Geophys. Surveys Report of Inv. 83-10, 3 sheets, 1:25000.

Coleman, R.G. and Burns, L.E., 1985, The Tonsina Complex, Chugach Mountains, a high-pressure mafic-ultramafic cumulate sequence [abs.]: Bulletin of the Geol. Soc. of Am., Cordilleran Section, v.17, no.6, p.348.

Crawford, M.L. and Hollister, L.S., 1982, Contrast of metamorphic and structural histories across the Work Channal linement, Coast Plutonic Complex, British Columbia: Journal of Geophys. Res., v.87, p.3849-3860.

Fuchs, W.A., 1980, Tertiary tectonic history of the Castle Mountain-Caribou fault system in the Talkeetna Mountains, Alaska: Ph.D. thesis, Univ. of Utah, Salt Lake City.

Grantz, A., 1964, Stratigraphic reconnaissance of the Matanuska Valley, Alaska: U.S. Geol. Surv. Bull., 1181-1, 11-133.

Grantz, A., 1966, Strike-slip faults in Alaska: U.S. Geol. Surv. Open File Rep., 82p.

Harris, L.B., and Cobbold, P.R., 1984, Development of conjugate shear bands during bulk simple shearing: Journal of Structural Geology, v.7, no.1, p.37-43.

Harrison, T.M., 1981, Diffusion of Ar in hornblende: Contributions to Mineralogy and Petrology, v.78, p.

324-331.

Harrison, T.M., and McDougall, I., 1980, Investigations of an intrusive contact, northwest Nelson, New Zealand-I, Thermal,chronilogical and isotopic constraints: Geochimica et Cosmochimica Acta, v.44, p.1985-2003.

Harrison, T.M., and McDougall, I., 1981, Excess Ar in metamorphic rocks from Broken Hill, New South Wales: Implications of Ar/ Ar age spectra and the thermal history of the region: Earth and Planetary Science Letters, v.55, p.123-149.

Hobbs, B.E., and Means, W.D., and Williams, P.F., 1976, An Outline of Structural Geology. John Wiley and Sons, New York, Chichester, Brisbane, Toronto, 571p.

Hudson, T.G., 1979, Mesozoic plutonic belts of southern Alaska: Geology, v.7, p.230-234.

Jones, D.L., and Silberling, N.J., 1979, Mesozoic stratigraphy-The key to tectonic analyses of southern and central Alaska: U.S. Geol. Surv. Open File Rep., 79-1200, 41.

Lanphere, M., 1978, Displacement of the Denali fault system, Alaska and Canada: Canadain Journal of Earth Sciences, v.15, p.817-822.

Law, R.D., and Knipe, R.J., 1984, Strain path partitioning within thrust sheets: microstructural and petrofabric evidence from the Moine Thrust zone at Loch Eriboll, northwest Scotland: Journal of Structural Geology, v.6, no.5, p.477-497.

Lister, G.S. and Price, G.P., 1978, Fabric development in a quartz-feldspar mylonite: Tectonophysics, v.49, p.37-38.

Lister, G.S. and Snoke, A.W., 1984, S-c mylonites: Journal of Structural Geology, v.6, no.6, p.617-638.

Lister, G.S., and Williams, P.F., 1979, Fabric development in shear zones: Theoretical controls and observed phenomena: Journal of Structural Geology, v.1, no.4, p.283-297.

MacKevett, E.M.Jr. and Plafker, G., 1974, The border ranges fault in south-central Alaska: Jour. Research U.S. Geol. Survey, v.2, no.3, 1974, p.323-329.

Mitra, Gautam, 1984, Brittle to ductile transition due to large strains along the White Rock thrust, Wind River Mountains, Wyoming: Journal of Structural Geology, v.6, no.1/2, p.51-61.

Monger, J.W.H. and Price, R.A., 1979, Geodynamic evolution of the Canadian Cordillera-progress and problems: Canadian Journal of Earth Sciences, v.16, p.770-791.

Pavlis, T.L., 1983, Pre-Cretaceous crystalline rocks of the western Chugach Mountains, Alaska: Nature of the basement of the Jurassic Peninsular terrane: Geol. Soc. of Am. Bull., v.94, p.1329-1344.

Pavlis, T.L., 1982, Origin and age of the border ranges fault of southern Alaska and its bearing on the Late Mesozoic tectonic evolution of Alaska: Tectonics, v.1, no.4, p.343-368.

Plafker, G., Nokleberg, W.J., Lull, J.S., Roback, R.C., Sisson, V.B., Pessel, G.H., Wallace, W.K., Pavlis, T.L., Winkler, G.R., and Coleman, R.B., 1985, Summary of the 1984 TACT geologic studies in the northern Chugach Mountains and southern Copper River basin, Preliminary Abstract, U.S.G.S. Circular.

Plafker, G., Jones, D.L., Pessagno, E.A. Jr., 1977, A Cretaceous accretionary flysch and melange terrane along the Gulf of Alaska margin: The U.S. Geological Survey in Alaska, Accomplishments during 1976, U.S. Geol. Surv. Circ., 751-B, B41-B43.

Platt, J.P. and Vissers, R.L.M., 1980, Extensional structures in anisotropic rocks: Journal of Structural Geology, v.2, no.4, p.397-410.

Ramsay, J.G., and Graham, R.H., 1970, Strain variation in shear belts: Canadian Journal of Earth Sciences, v.7, p.786-813.

Ramsey, J.G. and Huber, M.I., 1983, The Techniques of Modern Structural Geology Volume 1: Strain Analysis. Academic Press, 307p.

Simpson, Carol, 1984, Borrego Springs-Santa Rosa mylonite zone: A Late Cretaceous west directed thrust in southern California: Geology, v.12, p.8-11.

Simpson, C. and Schmid, S.M., 1983, An evaluation of criteria to deduce the sense of movement in sheared rocks: Geol. Soc. of Am. Bull., v.94, p.1281-1288.

Sibson, R.H., 1977, Fault rocks and fault mechanisms: Jour. Geol. Soc. of London, v.133, p.191-213.

Stauffer, M.R., editor, 1983, Fabrics of Ductile Strain; Benchmark Papers in Geology 75. Hutchinson Ross Publishing Co., Stroudsberg, PA, 400p.

Wallace, W.K., 1985, Tectonic evolution of the Haley Creek Terrane, a rootless thrust sheet in the Chugach Mountains, Alaska: Geological Society of America Abstracts with Programs, Cordilleran Section, v.17, no.6, p.416.

Wallace, W.K., 1981, Structure and petrology of a portion of a regional thrust zone in the Chugach Mountains, Alaska: Seattle, WA, University of Washington, Ph.D. dissertation, 253p.

White, S.H., Burrows, S.E., Carreras, J., Shaw, N.D., and Humphreys, F.J., 1980, On mylonites in ductile shear zones: Journal of Structural Geology, v.2, p.175-187.

Winkler, G.R., Silberman, M.L., Grantz, A., Miller, R.J. and MacKevett, E.M.Jr., 1981, Geologic map and summary geochronology of the Valdez Quadrangle, southern Alaska: U.S. Geological Survey, Open-File Report 80-892-A.

VITA

George Crouse was born on the planet earth. He enjoys cold beer, soft pretzels, and women with large breasts.

GEOLOGIC MAP OF A PORTION OF THE HALEY CREEK TERRANE

LEGEND

g	Alpine Glaciers and Snowfields
Qt	Quaternary Talus
Qg	Quaternary Glacial Deposits
Qu	Quaternary Undifferentiated Deposits
V	Valdez Group Phyllites and Metasandstones
p	Phyllite
m	Marble
qms	Quartz-rich Mica Schist
tg	Tonalite Gneiss
qfs	Quartzo-feldspathic Schist
tr	Trondhjemite Gneiss
ag	Amphibolite Gneiss
um	Ultramafics (hornblendite)

45 Strike and dip of inclined, vertical foliation

52 Trend and plunge of inclined, horizontal mineral lineations

87 Attitude of inclined, vertical joint set

27 Bearing and plunge of small fold axis

12 Trend of small folds, not mappable at this scale

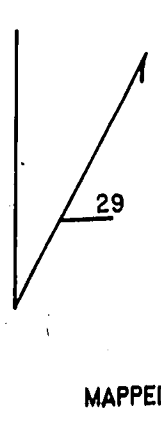
Geologic contact: Dashed where approximately located, dotted where inferred or covered.

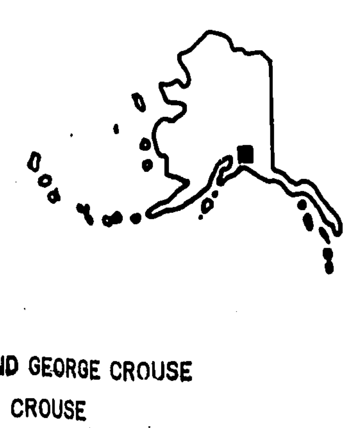
Major fault trace: Dashed where approximately located, dotted where inferred or covered.

SCALE 1:31680

1 1/2 0 1 MILE

CONTOUR INTERVAL 100 FEET





MAPPED BY TERRY PAVLIS AND GEORGE CROUSE

DRAFTED BY GEORGE CROUSE

PLATE I